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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- An Orbiter/Balloon Communication and
Tracking System for Obtaining Data on
the Venusian Atmosphere

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ABSTRACT

A simple and efficient orbiter/balloon communication
and tracking system for obtaining data on the Venusian
atmosphere is developed. Twelve meteorological balloons
immersed in the atmosphere, and a satellite (orbiter) in
orbit about Venus, will be the vehicles to collect, store,
and relay to Earth scientific data on the Venusian
atmosphere.

Instrumentation aboard the balloons will measure
various atmospheric parameters. This data will be stored
for eventual transmission to the orbiter.

The orbiter will operate in either the search mode
or the communication and tracking mode. Initially the search
mode is used to locate a balloon. When a balloon is located,
a two-way coherent radio link will be established for reading
out data stored aboard the balloon; this data then will be
stored aboard the orbiter. In addition, the orbiter will
determine the location of each balloon (range, range rate,
and angle) with respect to the orbiter and will store this
data. During each revolution, the orbiter will contact all
of the balloons and then relay the data to Earth via a second,
two-way coherent radio link.

Results of this study show that communicating with
and tracking the balloons by the orbiter, using two frequencies
on a time-sharing basis, is a feasible and efficient system.
Important parameters associated with this system are summarized
in Tables III and IV. This memorandum deals exclusively with
the orbiter/balloon links. A brief description of the orbiter/
Earth links is given in Reference 3.

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TECHNICAL MEMORANDUM

I.   INTRODUCTION

Meteorological balloons immersed in the Venusian atmosphere, and a satellite (orbiter) in orbit about Venus, will be the vehicles to collect, store, and relay to Earth scientific data on the Venusian atmosphere.

Instrumentation aboard the balloons will measure atmospheric temperature, pressure, humidity, local turbulence and local electrical activity. This data will be stored for eventual transmission to the orbiter.

The orbiter will operate in either the search mode or the communication and tracking mode. Initially, the search mode will be used to locate a balloon. When a balloon is located, a two-way coherent radio link will be established for reading out data stored aboard the balloon; this data then will be stored aboard the orbiter. In addition, the orbiter will determine the location of each balloon (range, range rate, and angle) with respect to the orbiter and will store this data. During each revolution, the orbiter will contact all of the balloons and then relay the data to Earth via a second, two-way coherent radio link.

Balloon and orbiter electronic systems for implementing this project are developed in this memorandum. The overall balloon/orbiter communication and tracking system developed here is an updated version of a system proposed earlier.[1] The updated system offers a simpler and more efficient design compared to the earlier system.

For completeness, the initial deployment of the orbiter/balloon system is summarized in the next section; the deployment is treated in detail in References 2 and 3. Overall operation of the orbiter/balloon communication and tracking system is presented in Section III. The orbiter and balloon electronic systems are described in Section IV. Systems analysis pertaining to the orbiter/balloon two-way radio link is performed in Section V. Weight, size and power requirements are discussed in Section VI. Lastly, conclusions pertaining to the overall system, and a summary of important system parameters are presented.

II. DEPLOYMENT OF ORBITER AND BALLOONS[2,3]

The orbiter, and two probes carrying six balloons each, will be deployed from a (manned or unmanned) Venus flyby vehicle.

One possible strategy would require the probe to release its balloons near the sub-Earth point; the other probe would release its balloons near the anti-Earth point. The balloons could be deployed at specific heights between, say, five and forty-five kilometers. Planned lifetime of the balloons is thirty days. If turbulent conditions exist, the balloons may become widely dispersed in the atmosphere during this time period.

The orbiter will be placed in a 4000 kilometer altitude, circular orbit. One revolution will occur every 185 minutes (equivalent to an angular rate of 1.95 degrees per minute). During each revolution, the orbiter will attempt to acquire and communicate with the twelve balloons on a time-sharing basis. The initial orbiter/balloon configuration is shown in Figure 1.

III. OPERATION OF THE ORBITER/BALLOON ELECTRONIC SYSTEMS

A. General

In this design, the orbiter contacts the balloons on a time-sharing basis. Thus, only one pair of frequencies is required to establish a two-way link between the orbiter and any balloon. A simple, efficient, highly reliable, and minimum cost system results from this design approach because (a) only one carrier tracking loop, voltage controlled oscillator (VCO) is required in each balloon electronic system and in the orbiter electronic system, and (b) an identical electronic system can be used aboard all balloons. Figures 2 and 3 depict the orbiter and balloon electronic systems.

Operation of the entire orbiter/balloon system in both the search mode and the communications and tracking mode is controlled by the programmer. The programmer logic (Figure 4) is explained below.

B. Orbiter Search Mode

Prior to locating a balloon, the orbiter operates in the search mode. A fan beam, formed by the orbiter phased array, is selected to give a wide beamwidth (55°) in the cross-orbit plane. Thus, as the orbiter revolves about Venus, the fan beam illuminates a large band in which the balloons will most likely be located. After selection of the fan beam, the orbiter transmitter VCO is swept once through its entire frequency range and then the VCO is returned to its nominal center frequency. Simultaneously, the overflow counter is set to the number, 1.

By using the fan beam and a complete sweep of the transmitter VCO, a number of balloon receivers may have locked-up to the carrier. The programmer next instructs the address and command encoder to address balloon number K, where K is an integer between 1 and 12; the initial setting of the address counter is immaterial. (If balloon number K receives its address, the balloon turns on its transmitter.) The programmer next activates continuous sweep of the orbiter receiver VCO to search for a received carrier from balloon number K.

If an in-lock indication of the orbiter receiver phase lock loop is not achieved within a specified time period, the programmer logic surmises that balloon number K was not illuminated by the fan beam. Other balloons may have been illuminated, however, and these balloon receivers should be in-lock due to the initial frequency sweep of the transmitter. Thus, the programmer steps the address counter and overflow counter by one count. Since the overflow counter does not overflow (an overflow would have occurred if its setting were 12), a "no overflow" pulse initiates the transmittal of balloon address number (K + 1). The loop described here is cycled up to a total of twelve times. If twelve unsuccessful balloon interrogations occur, the overflow counter generates an "overflow" pulse that initiates another single sweep of the orbiter transmitter VCO. Since the fan beam has swept ahead during this time interval due to the orbiter's motion, a number of balloons may lock-up on this transmitter VCO sweep. The address of balloon number K is repeated and sweep of the receiver VCO is initiated as before.

The process described above repeats itself until a balloon is acquired. When a balloon is acquired, i.e. the orbiter receiver locks to a received carrier, the programmer enters the communication and tracking mode (Figure 4) as described below. In this manner, all balloons should be acquired once during each revolution of the orbiter.

C.   Orbiter Communications and Tracking Mode

When the orbiter receiver locks to a received carrier, the sweep of the receiver VCO is automatically terminated. Then the conical beam is selected; the beam tracks the received carrier. A command to switch to low power and initiate data transmission is transmitted to the balloon. After this command, range code transmission by the orbiter begins.

The range code is transponded at the balloon where it is combined with a 10 kHz data subcarrier; the combined signal is transmitted to the orbiter. Scientific data received from the balloon, and range, velocity, and beam tracking angle data are formatted and sent to the orbiter's data storage for eventual

transmission to Earth. Upon conclusion of data reception, the programmer terminates range code transmission and sends a command to turn off the balloon transmitter.

Next, the address counter is stepped by one count (note that the address counter is not returned to K=1), and the overflow counter is reset to the number, 1. The fan beam is selected and the search mode is operative as described in Paragraph III-B. The search mode is needed since other balloon receivers that may have been acquired during the previous search period probably would have lost lock when the array was switched to the conical beam of the communications and tracking mode.

IV.   DESCRIPTION OF THE ORBITER AND BALLOON ELECTRONIC SYSTEMS

A.   General

A concise description of the orbiter and balloon electronic systems is given below.

B.   The Orbiter Electronic System

The orbiter electronic system (Figure 2) consists of the following subsystems:

(a) programmer and timing;

(b) diplexer, and a multiple beam, phased array antenna;

(c) S-band transmitter and phase-locked receiver;

(d) subcarrier demodulator;

(e) VCO sweeper;

(f) address and command encoder;

(g) digital ranging generator;

(h) doppler extractor;

(i) angle encoder;

(j) data storage.

The programmer is the computer control center of the orbiter. As described in Section III, switching of the antenna beam, sweeping of the transmitter or receiver VCO, operation of the address and command encoder, and operation of the digital ranging generator and doppler extractor are controlled according

to a sequence entered into the programmer prior to launch. Also, an accurate timing system (long term combined accuracy and stability = $\pm 10^{-6}$) is incorporated in this subsystem to furnish clock signals to the programmer and a reference frequency to the S-band transmitter.

The phased array antenna provides either a fan beam or a conical beam; selection of the desired beam is controlled by the programmer. When the orbiter is searching for a balloon (search mode), the fan beam is used because it has a wide beamwidth (55 degrees) in the cross-orbit plane. To further facilitate search, the beam is pointed 5 degrees forward of local vertical. Once a balloon is located, the programmer selects the conical (high gain) beam which is used for communicating with and tracking the balloon (communication and tracking mode). Increased gain afforded by the conical beam compensates for lower balloon transmit power in this mode, and for modulation loss of the carrier.

The antenna consists of a 10 x 10 matrix of transmitting/receiving elements. Each element is a six-turn helix; the elements are spaced by about $\lambda/2$. By selecting a circumference of 1λ and a spacing between turns of 0.15λ, the resultant half power beamwidth of each helix is 55 degrees and the gain is 11.3 db.[4]

Formation of the fan beam is achieved by activating only a 10 x 1 submatrix of the antenna; the long dimension of this submatrix is parallel to the in-orbit plane. The resultant beamwidth is 55 degrees in the cross-orbit plane, and 10 degrees in the in-orbit plane. The in-orbit beamwidth meets the requirements derived in Paragraph V-B. Gain of the fan beam[5] is 16.6 db; however, the orbiter must be capable of locating a balloon at any corner point of the fan beam and therefore the worst case gain is 6 db lower. Thus, a gain of 10.6 db is used in the link calculations in the Appendices. If a balloon is within the fan beam, but is not located at a corner of the fan beam, the increased gain serves as a safety margin over the results obtained in the link calculations.

All elements of the 10 x 10 matrix are activated to form the conical beam; an ideal gain of 31.3 db is obtained. Allowing degradations of 2.3 db due to imperfect phasing, 4.0 db for beam shaping and ohmic losses, 0.5 db for tracking error, and 0.5 db for beam spreading[6] at ± 27.5 degrees from local vertical, yields an actual (worst case) gain of 24 db and a beamwidth (3 db) of 10 degrees.

The S-band transmitter is phase-locked to the high stability reference frequency from the timing subsystem. Upon direction from the programmer, the transmit carrier either may

be swept across the necessary sweep range to acquire balloon receiver phase lock loops, or may be phase modulated by one of the following:

(a) an address word (10 bits at 600 bps),

(b) a command word (10 bits at 600 bps), or

(c) the ranging code (10 kbps continuous).

The receiver must be swept across the necessary sweep range to acquire a carrier received from a balloon. If a carrier is received, the sweep is terminated and the receiver locks to the carrier. The receiver coherently demodulates the signal, and delivers the resultant data subcarrier to the subcarrier demodulator and the ranging signal to the digital ranging generator. Certain coherent frequencies derived in the transmitter and receiver are sent to the doppler extractor for processing.

While in the search mode, the VCO sweeper first performs one sweep of the transmitter VCO. Then the address and command encoder addresses one balloon at a time. (If a balloon is illuminated by the fan beam and receives its particular address, the balloon reacts by turning on its transmitter.) Simultaneously the VCO sweeper begins to sweep the receiver VCO to search for a return carrier. Once two-way lock-up of the orbiter/balloon communication link is achieved, sweep of the receiver VCO is terminated by the programmer.

The address and command encoder then sends commands to the balloon to switch to low power and initiate data readout. At the end of data readout, a command is sent to turn off the balloon transmitter. These command words are common for all balloons - only the address word is different for each balloon.

The subcarrier demodulator detects the digital data and then delivers it to the orbiter's data storage subsystem.

During the balloon data readout period, the programmer enables the digital ranging generator and the doppler extractor. A pseudo noise (PN) ranging code is transmitted to the balloon where the code is transponded back to the orbiter. The digital ranging generator detects the received code and determines the delay of the received code relative to the transmitted code. The round trip delay is equivalent to range. Range data, derived by this technique, is delivered to the data storage subsystem. The expected range accuracy is $\pm$ 1.0 km.

The doppler extractor determines the relative velocity between the balloon and the orbiter. Doppler is derived by manipulating the transmit and receive frequencies which are coherently related. Velocity data is sent to the data storage subsystem. The expected velocity accuracy is $\pm$ 0.5 meters/second.

The angle encoder senses the direction of the conical beam, and furnishes a digital readout to the data storage sub-system. The expected angle accuracy is ± 1 degree.

Thus, the data storage subsystem collects and formats scientific data received from the balloons and position data of the balloons with respect to the orbiter. Once during each orbit, a command is received from Earth to readout the stored data for transmittal to Earth.

C. The Balloon Electronic System

The balloon electronic system (Figure 3) consists of the following subsystems:

(a) diplexer and widebeam antenna,

(b) phase-locked S-Band transponder,

(c) address and command decoder,

(d) data storage,

(e) subcarrier modulator,

(f) timing and logic, and

(g) transmitter monitor and destruct.

Since the balloons may be subjected to high winds, an antenna, having a wide beamwidth (3 db) of 100°, is used to insure reliable communications with the orbiter.

The S-band transponder coherently derives its transmit frequency from the receive frequency (the turn-around frequency ratio is $\frac{240}{221}$). While a coherent transponder requires an acquisition procedure, the coherent feature offers accurate range and velocity measurements aboard the orbiter. This added capability more than offsets the difficulty of acquisition. The transponder also accepts the data subcarrier. The resultant baseband, consisting of the ranging code and data subcarrier, phase modulates the balloon transmit carrier.

The address and command decoder detects address or command words which are phase modulated on the received carrier. Each balloon has a preset address word stored in the decoder. If this address is received, the balloon turns on its transmitter at full power. Subsequent command words reduce the transmit power (after two-way lock-up at the orbiter), initiate data

transmission, and finally turn off the transmitter. Command words are the same for each balloon; these commands are not accepted, however, unless the correct address word has been received first.

The data storage subsystem retains up to 800 bits of scientific information (including the balloon's address word which tags the data). When the appropriate command word is received from the orbiter, the data is dumped in serial form to the subcarrier modulator. The digital data phase shift keys (PSK) a 10 kHz subcarrier at a rate of 60 bps.

A timing and logic subsystem inhibits balloon transmission for the twenty minute period immediately following turnoff of the balloon transmitter. Thus, the orbiter cannot acquire the same balloon more than once during each orbit. The timing and logic subsystem also activates a destruct mechanism if the transmitter does not turn off after a four hour period. The destruct feature is required since all balloons transmit the same frequency which must be time-shared to prevent interference at the orbiter.

V.   SYSTEMS ANALYSIS

A.   Worst Case Time Required for the Orbiter to Acquire and Process Six Balloons

The worst case time required for the orbiter to acquire and process six balloons is calculated here so that the minimum required in-orbit beamwidth of the fan beam can be calculated in Paragraph V-B.

The cross-orbit beamwidth of the fan beam is fixed at 55°. To maximize the gain of the fan beam, the in-orbit beamwidth must be minimized. Minimum beamwidth is constrained by the requirement that the in-orbit beamwidth must be sufficiently large such that six closely grouped balloons (at the sub-Earth point, for example) can be acquired and processed by the orbiter as it passes over the balloons' location. Note that any dispersal of balloons in the in-orbit plane eases the constraint on minimum in-orbit beamwidth, and thus the above balloon configuration (corresponding to initial deployment) is a worst case condition for the orbiter.

In addition, two other worst case conditions are imposed as follows:

    (a) A sweep of the orbiter transmitter VCO occurs just prior to illumination of the six balloons by the fan beam; the fan beam is moving at the speed of the orbiter (1.95° per minute). (Thus a sequence of twelve unsuccessful interrogations occurs before the next transmit VCO sweep acquires the balloon receiver phase lock loops (see Paragraph III-B).)

(b) The six balloons, that are illuminated by the fan beam during the <u>next</u> transmit VCO sweep, respond to the last six addresses sent by the orbiter. (Thus an additional six unsuccessful addresses are sent by the orbiter before the first balloon responds.)

The worst case required time is defined as the time between the start of (a) and the conclusion of (b). Note from Paragraph III-B and Figure 4 that acquisition and processing time for each balloon is constant regardless of its order in the address sequence. Thus (b) is truly a worst case condition.

Tables I and II are compiled by determining the time required to accomplish (a) and (b) respectively (refer to Figure 4); the results then are added together to determine the total worst case time to acquire and process the six balloons. Therefore, T_o equals 198,000 msec (198 sec.).

B.   Required Orbiter Fan Beamwidth in the In-Orbit Plane

The fan beam must illuminate a point target area for at least 198 seconds. A minimum in-orbit beamwidth (3 db) for meeting the requirement is derived below.

The orbiter ground speed is:

$$R\dot{\phi} = 206 \text{ km/minute}$$

where:

$$R = \text{radius of Venus} = 6050 \text{ km}$$

$$\dot{\phi} = \text{orbiter angular rate} = 1.95 \text{ degrees/minute}$$
$$(0.034 \text{ rad/min.})$$

Now, the required 3 db beamwidth (θ) in the in-orbit plane is determined as follows:

$$r\theta = R\dot{\phi} \, T_o$$

where:

$$r = \text{orbiter altitude} = 4000 \text{ km}$$
$$T_o = 3.3 \text{ minutes (198 sec.)}$$

Therefore, $\theta = 10$ degrees.

C. Link Calculations

Link calculations pertinent to the orbiter/balloon links in both the search mode and communications and tracking mode are presented in Appendices I to IV. From these calculations, all important equipment parameters necessary to acquire and establish the two-way orbiter/balloon links are derived. A summary of all parameters is presented in Section VII.

VI.   WEIGHT, SIZE AND POWER

Anticipated values of weight, size, and prime power for the orbiter and balloon electronic subsystems (using technology projections for the mid 1970s) are presented in Table III.

VII.   SUMMARY AND CONCLUSIONS

A simple and efficient orbiter/balloon communications and tracking system has been developed conceptually here. Scientific data from twelve balloons immersed in the Venusian atmosphere, and balloon position data derived aboard the orbiter, are relayed to Earth once during each revolution of the orbiter. This memorandum has dealt exclusively with the orbiter/balloon links. Critical parameters associated with these links, as derived in the text and in the Appendices, are summarized in Table IV.

A brief description of the orbiter to Earth link is given in Reference 3. A data rate of 5 bps is obtainable when using an omni-directional antenna and a transmitter requiring 70 watts of prime power on the orbiter. By processing both orbiter ephemeris data, and telemetered balloon position data (range, range rate, and angle of each balloon with respect to the orbiter), Earth-based computers can calculate the position of each balloon with respect to the Venusian surface. That is, each balloon position can be transformed into a Venus-oriented coordinate system. Thus, by determining the position of each balloon as a function of time, empirical data on Venusian wind patterns and velocities can be obtained.

This study shows that communicating with and tracking twelve meteorological balloons by an orbiter, using two frequencies on a time-sharing basis, is feasible. Reasonable transmitted powers, antenna sizes, and other parameters (as outlined in Table IV) constitute this system.

K. H. Schmid

2034-KHS-rkw   K. H. Schmid

Attachments

TABLE I

TIME REQUIRED FOR UNSUCCESSFUL INTERROGATION OF TWELVE BALLOONS

(Condition a)

1.	Overflow Pulse and One Sweep of Transmitter VCO (120 kHz at 20 kHz/sec.*)		6,000 msec
2 a.	Address Balloon (delay, plus 10 bits at 600 bps); Initiate RCVR VCO Sweep	50 msec	
b.	Anticipated Two-way Propagation Time	30 msec	
c.	Anticipated Address Decode Time	50 msec	
d.	Anticipated Balloon XMTR Turn On Time	800 msec	
e.	Anticipated Orbiter RCVR Lock-up Time Plus Safety Margin	1,000 msec	
f.	Step Address and Overflow Counters and Return to 2a	70 msec	
g.	Total Time (T) Allotted per Balloon for Response	2,000 msec	
h.	Total Time Allotted for Twelve Balloons to Respond		24,000 msec
3.	Time Required for Unsuccessful Interrogation of Twelve Balloons		30,000 msec

*See Paragraph V-C.

TABLE II

TIME REQUIRED FOR UNSUCCESSFUL INTERROGATION OF SIX BALLOONS
FOLLOWED BY SUCCESSFUL INTERROGATION OF SIX BALLOONS

(Condition b)

1.   Overflow Pulse and One Sweep of
     Transmitter VCO (120 kHz at
     20 kHz/sec.)   6,000 msec

2.   Address Six Balloons Unsuccessfully
     (2000 msec/balloon, see 2g of
     Table I)   12,000 msec

3a. Address Next Balloon Successfully
     (2000 msec max., see 2g of Table I)   2,000 msec

 b. Switch to Conical Beam   500 msec

 c. Command Balloon to Switch to Low
     Power and Begin Data Transmission;
     Initiate Ranging at Orbiter; Receive
     Ranging; Receive Data (800 bits at
     60 bps)   15,000 msec

 d. Command Balloon XMTR to Turn Off   1,000 msec

 e. Switch to Fan Beam; Step Address
     Counter; Reset Overflow Counter
     to 1   500 msec

 f. One Sweep of Transmitter VCO and
     Return to 3a   6,000 msec

 g. Total Time Required to Process
     One Balloon Successfully   25,000 msec

 h. Total Time Required to Process
     Six Balloons Successfully   150,000 msec

4.   Total Time Required for Unsuccess-
     ful Interrogation of Six Balloons
     Followed by Successful
     Interrogation of Six Balloons   168,000 msec

TABLE III

ANTICIPATED WEIGHT, SIZE, AND PRIME POWER FOR THE BALLOON AND ORBITER ELECTRONIC SYSTEMS

Equipment	Orbiter			Balloon		
	Weight (pounds)	Size (cu. in.)	Prime Power (watts)	Weight (pounds)	Size (cu. in.)	Prime Power (watts)
Antenna and Diplexer	110	10 (cu.ft.)	N.A.	3.5	1 (cu.ft.)	N.A.
XMTR/RCVR	5	400	15	5	400	25 (search mode) 3 (comm & tracking mode)
Ranging and Doppler Extractor	15	200	10	N.A.	N.A.	N.A.
Data Storage	5	200	2	0.5	10	0.5
Other (see Figs. 2,3)	8	160	15	4	100	2.5
Total	143	960*	42	13	510*	28 (search mode) 6 (comm. & tracking mode)

*Excluding Antenna and Diplexer
N.A. = Not Applicable

TABLE IV

SUMMARY OF PARAMETERS

Parameter	Orbiter to Balloon Link		Balloon to Orbiter Link	
	Search Mode	Comm. & Tracking Mode	Search Mode	Comm. & Tracking Mode
Frequency	2100 MHz	2100 MHz	2300 MHZ	2300 MHz
Orbiter Antenna	Fan Beam	Conical Beam	Fan Beam	Conical Beam
Orbiter Antenna Gain	10.6 db	24.0 db	10.6 db	24.0 db
Orbiter Line Loss	2 db	2 db	2 db	2 db
Space Loss	172.2 db	172.2 db	173.0 db	173.0 db
Balloon Antenna Gain	1 db	1 db	1 db	1 db
Balloon Line Loss	2 db	2 db	2 db	2 db
Min. CNR in $2B_L$	10 db	10 db	10 db	10 db
Rec. System Noise Temp.	1700°K	1700°K	2350°K	2350°K
Sweep Range (Orbiter)	120 kHz (XMTR)	N.A.	15 kHz (RCVR)	N.A.
Sweep Rate (Orbiter)	20 kHz/sec.	N.A.	20 kHz/sec.	N.A.
$2B_L$	830 Hz	830 Hz	830 Hz	830 Hz
Req. Carrier-to-Noise Density Ratio	38.3 db	38.3 db	38.3 db	38.3 db
Req. Ranging Signal-to-Noise Density Ratio	N.A.	38.0 db	N.A.	30.0 db
Req. Data S/C Signal-to-Noise Density Ratio	N.A.	N.A.	N.A.	24.8 db
Ranging Mod Index	N.A.	0.7	N.A.	0.35
Data S/C Mod Index	N.A.	N.A.	N.A.	0.30
Transmitter Power	3 watts	3 watts	5 watts	0.6 watts
Carrier Circuit Margin	0 db	11.1 db	0 db	3.1 db
Ranging Circuit Margin	N.A.	9.9 db	N.A.	1.5 db
Data S/C Circuit Margin	N.A.	N.A.	N.A.	1.5 db

SEARCH FAN BEAM

4,000 KM ALTITUDE
CIRCULAR ORBIT

CONICAL BEAM

SUB-SOLAR
POINT

EQUATOR

BALLOON
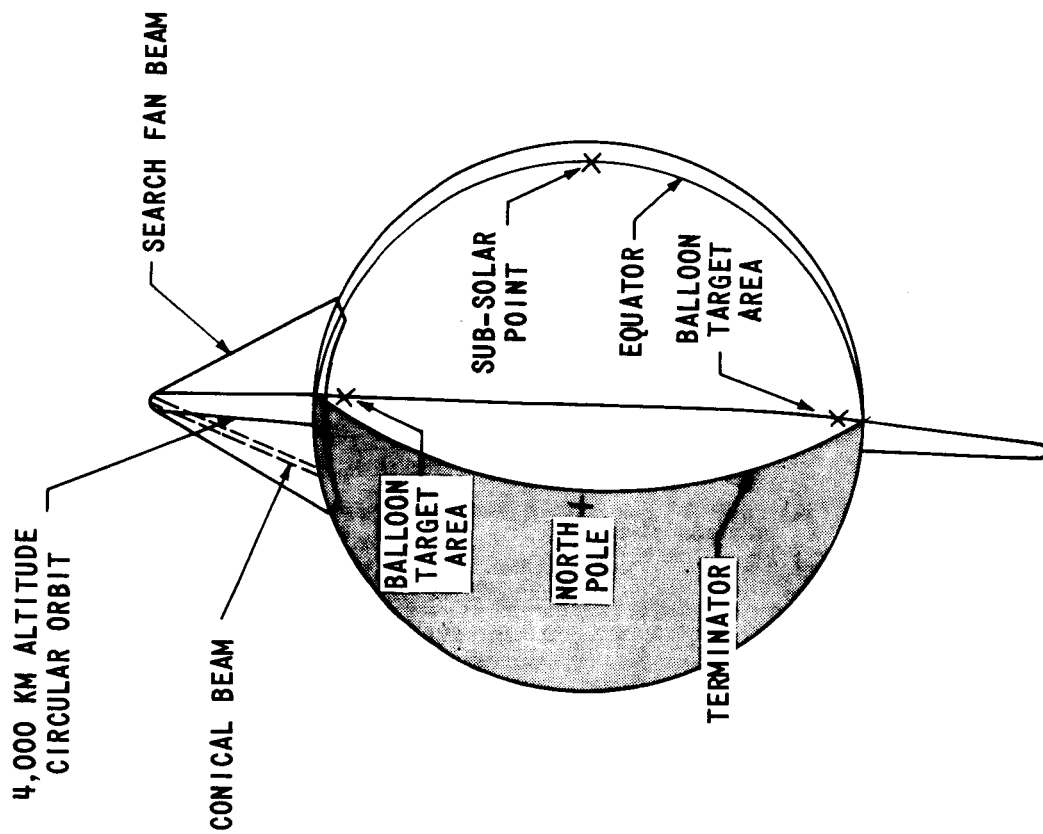TARGET
AREA

BALLOON
TARGET
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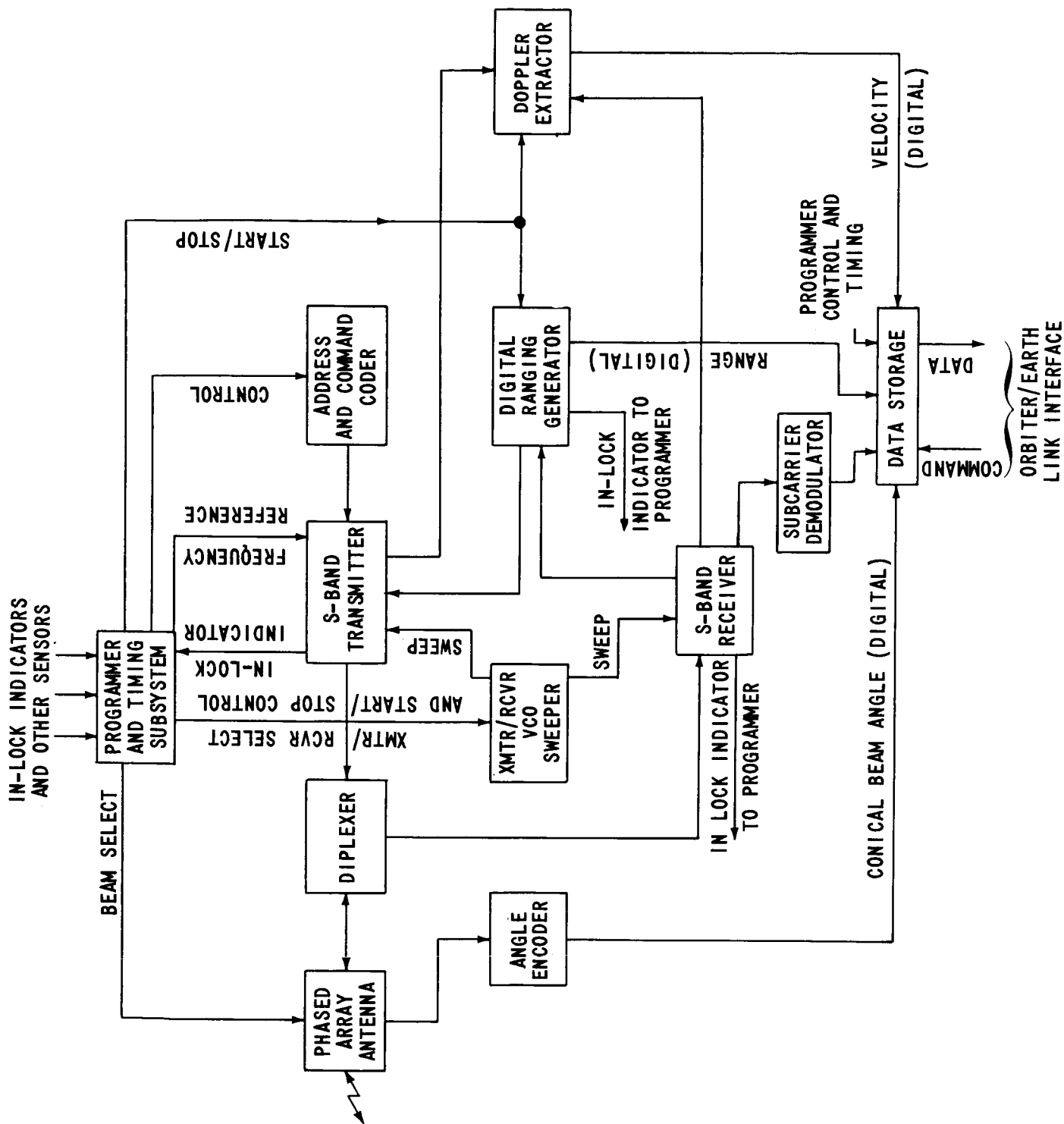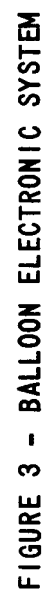POLE

TERMINATOR

FIGURE 1 – ORBITER/BALLOON CONFIGURATION

FIGURE 2 - ORBITER ELECTRONIC SYSTEM (ORBITER/BALLOON LINK)

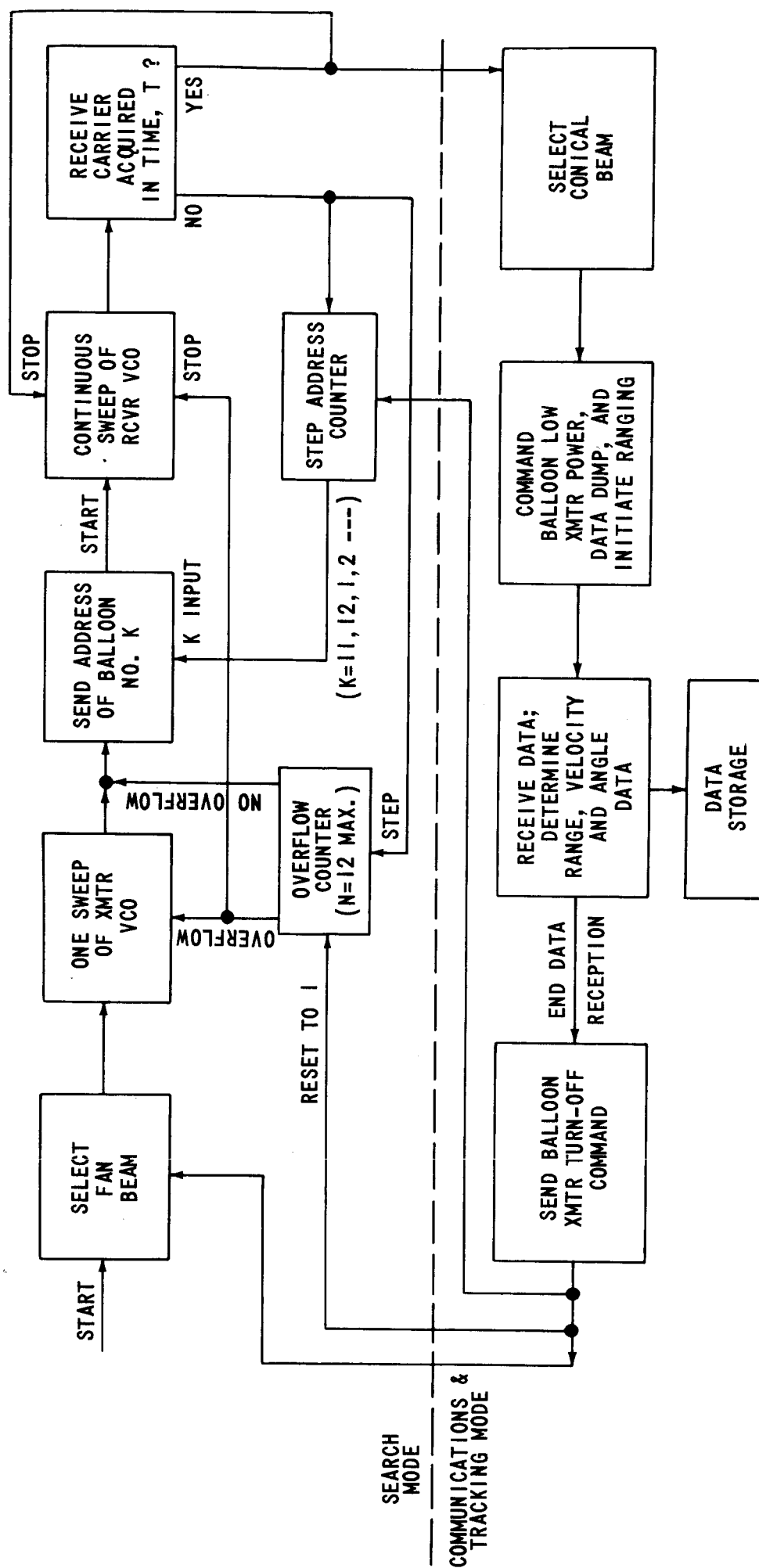FIGURE 3 - BALLOON ELECTRONIC SYSTEM

FIGURE 4 - PROGRAMMER LOGIC DIAGRAM

APPENDIX I

ANALYSIS OF THE ORBITER TO BALLOON LINK IN THE SEARCH MODE

A. General

Important parameters assigned to this link are listed in Table I-1.

Using these parameters, the required orbiter transmitter sweep range, balloon carrier tracking loop bandwidth, and orbiter transmitter power are calculated below.

B. Required Orbiter Transmitter Sweep Range

Since the balloon carrier tracking loop VCO frequency is the dominant frequency uncertainty ($\pm 2.5 \times 10^{-5}$) on the link, a large sweep of the orbiter transmitter VCO is required to lock-up this loop. The required sweep is given by:

$$\Delta f_1 = f_{LO} \cdot 5 \times 10^{-5} = 102{,}500 \text{ Hz}$$

where:

$$f_{LO} = \text{L.O. frequency of the balloon receiver}$$
$$= 2050 \text{ MHz}$$

An additional sweep range, $\Delta f_2 = 17{,}500$ Hz, is provided to allow for doppler and a safety factor. Doppler effects are minimal, since the fan beam is pointed only five degrees forward of local vertical and thus the radial velocity of each balloon with respect to the orbiter is very small.

The total required sweep, centered on the nominal frequency of 2100 MHz, is the sum of Δf_1 and Δf_2.

Therefore,

$$\Delta f = 120 \text{ kHz}$$

C. <u>Required Balloon Receiver Carrier Tracking Loop Bandwidth</u>

The balloon carrier tracking loop bandwidth must be wide enough to acquire a received carrier swept at 20 kHz/second. Ninety percent probability of acquisition is afforded if the limiter/loop parameters satisfy the following equation:[7]

$$\Delta\dot{\omega} = \left(1 - \frac{1}{\sqrt{CNR_L}}\right) \frac{\alpha}{\alpha_0} \omega_{no}^2$$

where:

$\Delta\dot{\omega}$ = carrier sweep rate (rad/sec)/sec = $2\pi (20 \cdot 10^3)$

CNR_L = carrier-to-noise ratio in $2B_L$ = 10 db

α = limiter suppression factor (at CNR_L = 10 db)

α_0 = limiter suppression factor (at CNR_L = 0 db)

ω_{no} = loop natural frequency (at CNR_L = 0 db)

Loop threshold is defined as CNR_L = 0 db in $2B_{Lo}$, where $2B_{Lo}$ is the two-sided loop noise bandwidth at threshold (second order loop).

Let α/α_0 = 3.65. Solving the above equation for ω_{no} yields,

$$\omega_{no} = 225 \text{ rad/sec}$$

Now

$$2B_{Lo} = 1.06 \ \omega_{no} = 238 \ Hz$$

To achieve nearly a 100% probability of acquisition and also provide a safety factor, the value of $2B_{Lo}$ is increased to,

$$2B_{Lo} = 300 \ Hz$$

Now,

$$2B_L = \frac{2B_{Lo}}{3} \ (\frac{2\alpha}{\alpha_o} + 1) = 830 \ Hz$$

when $CNR_L = 10$ db.

D. Required Carrier-to-Noise Density Ratio

A limiter, having a 10 kHz noise bandwidth, precedes the balloon receiver phase lock loop. For a required $CNR_L = 10$ db in $2B_L = 830$ Hz, the equivalent CNR at the output of the limiter is given by:

$$(CNR_{out})_{req} = 10 \ db - 10 \ \log \frac{10000}{830} = -0.8 \ db$$

The required CNR at the input to the limiter is related to CNR_{out} by:[7]

$$CNR_{out} = CNR_{in} \frac{1 + 2 \ CNR_{in}}{\frac{4}{\pi} + CNR_{in}}$$

Solving for CNR_{in} yields,

$$(CNR_{in})_{req} = -1.7 \text{ db (in the 10 kHz noise bandwidth)}$$

Therefore, the required carrier-to-noise density ratio is given by,

$$(CNR_o)_{req} = 38.3 \text{ db (in a 1 Hz bandwidth)}.$$

E.   <u>Balloon Receive System Noise Temperature</u>

The system noise temperature (referenced to the receive output of the balloon antenna) is given by:

$$T_{sys} = T_{ant} + (FL-1)\ 290°$$

where:

T_{ant} = balloon antenna temperature $\overset{\sim}{\sim}$ 150° K

F   = balloon receiver noise figure = 6 db

L   = balloon line loss = 2 db

Therefore,

$$T_{sys} = 1700°K.$$

F.   <u>Required Orbiter Transmitter Power</u>

The required orbiter transmitter power is calculated in Table I-2.

TABLE I-1

Orbiter to Balloon Link Parameters for the Search Mode

a.	Frequency (nominal)	2100 MHz
b.	Frequency Stability and Accuracy of Orbiter Transmitter (long term)	$\pm 10^{-6}$
c.	Orbiter Transmitter Sweep Rate	20 kHz/sec.
d.	Orbiter Line Loss	2 db
e.	Orbiter Transmit Antenna Gain (at 6 db corner points of fan beam)	10.6 db
f.	Path Length (maximum)	4600 km
g.	Balloon Receive Antenna Gain (at 3 db points)	1 db
h.	Balloon Line Loss	2 db
i.	Balloon Receiver Noise Figure	6 db
j.	Minimum CNR_L in 2 B_L*	10 db
k.	Frequency Stability and Accuracy of Balloon Carrier Tracking Loop VCO	$\pm 2.5 \cdot 10^{-5}$
l.	Balloon Receiver Limiter Bandwidth	10 kHz

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*CNR_L is the carrier-to-noise ratio in $2B_L$, the receiver two-sided loop noise bandwidth at levels above threshold.

TABLE I-2

Calculation of Required Orbiter Transmitter Power in the Search Mode

Required Carrier-to-Noise Density Ratio $(CNR_o)_{req}$
  at Receive Output of Balloon Antenna   38.3 db

Noise Density at Receive Output of Balloon
  Antenna $(T_{eff} = 1700°K)$ −166.3 dbm/Hz

Required Carrier Power at Receive Output of
  Balloon Antenna   −128.0 dbm

Balloon Antenna Gain   1.0 db

Space Loss (4600 km)   172.2 db

Orbiter Antenna Gain (fan beam)   10.6 db

Orbiter Line Loss   <u>2.0 db</u>

Required Orbiter Transmitter Power   34.6 dbm

                                                 $\approx$3 watts.

APPENDIX II

ANALYSIS OF THE BALLOON TO ORBITER LINK IN THE SEARCH MODE

A. General

Important parameters associated with this link are presented in Table II-1. Using these parameters, the required orbiter receiver sweep range, loop bandwidth, and balloon transmitter power are calculated. In item (j), note that the frequency stability and accuracy of the orbiter carrier tracking loop VCO is an order of magnitude better than the balloon carrier tracking loop VCO.

B. Required Orbiter Receiver Sweep Range

Since the balloon has a coherent transponder and the orbiter's transmit frequency is locked to a high stability frequency reference, the orbiter receive frequency is known to a high degree of accuracy. By sending a sample of the orbiter transmit frequency to the orbiter receiver system, almost all uncertainty in this frequency is removed. Thus, the required sweep range must allow only for orbiter receiver VCO drift and minor doppler variations.

The orbiter receiver VCO has a frequency stability and accuracy of $\pm 2.5 \cdot 10^{-6}$. Thus,

$$\Delta f_1 = f_{LO} (5 \cdot 10^{-6})$$

where:

f_{LO} = L.O. frequency of the orbiter receiver = 2250 MHz

Therefore,

$$\Delta f_1 = 11,250 \text{ Hz}$$

An additional sweep range, Δf_2, equal to 3750 Hz is provided to allow for all other uncertainties. Therefore, the total sweep range is,

$$\Delta f = \Delta f_1 + \Delta f_2 = 15 \text{ kHz}$$

Since the orbiter receiver VCO sweep rate is 20 kHz/sec, the maximum lock-up time is 3/4 second.

C.   Required Orbiter Receiver Carrier Tracking Loop Bandwidth and Carrier to Noise Density Ratio

Since the orbiter receiver sweep rate, the minimum CNR_L in $2B_L$, and the limiter bandwidth are identical to the values used in Appendix I, the same results are obtained. Thus,

$$2B_L = 830 \text{ Hz} \quad (\text{with } CNR_L = 10 \text{ db})$$

and

$$(CNR_o)_{req} = 38.3 \text{ db} \quad (\text{referenced to 1 Hz}).$$

D.   Orbiter System Noise Temperature

The orbiter effective system noise temperature (referenced to the receive output of the orbiter antenna) is given by:

$$T_{eff} = T_{ant} + (FL - 1) \, 290°$$

where these parameters have been defined earlier. Using an antenna temperature of 800°K yields,

$$T_{eff} = 2350°K$$

E.   Required Balloon Transmitter Power in the Search Mode

The required balloon transmitter power in the search mode is calculated in Table II-2. Note that this power is required for only 2.5 seconds (approximately) until the orbiter acquires the balloon carrier, switches to the communication and tracking mode, and commands the balloon to switch to low power.

TABLE II-1

Balloon to Orbiter Link Parameters for the Search Mode

a.	Frequency (nominal)	2300 MHz
b.	Frequency Stability and Accuracy of Transponded Carrier (long term)	$\pm 10^{-6}$
c.	Balloon Line Loss	2 db
d.	Balloon Transmit Antenna Gain (at 3 db point)	1 db
e.	Path Length (maximum)	4600 km
f.	Orbiter Receive Antenna Gain (at 6 db corner points of fan beam)	10.6 db
g.	Orbiter Line Loss	2 db
h.	Orbiter Receiver Noise Figure	6 db
i.	Minimum CNR_L in $2B_L$	10 db
j.	Frequency Stability and Accuracy of Orbiter Carrier Tracking Loop VCO	$\pm 2.5 \cdot 10^{-6}$
k.	Orbiter Receiver Sweep Rate	20 kHz/sec
l.	Orbiter Receiver Limiter Bandwith	10 kHz

TABLE II-2

Calculation of Required Balloon Transmitter Power in the Search Mode

Required Carrier-to-Noise Density Ratio
   $(CNR_o)_{req}$ at Receive Output of Orbiter Antenna   38.3 db

Noise Density at Receive Output of Orbiter
   Antenna (T_{eff} = 2350°K)   -164.9 dbm/Hz

Required Carrier Power at Receive Output of
   Orbiter Antenna   -126.6 dbm

Orbiter Antenna Gain (fan beam)   10.6 db

Space Loss (4600 km)   173.0 db

Balloon Antenna Gain   1.0 db

Balloon Line Loss   2.0 db

Required Balloon Transmitter Power   36.8 dbm

                                                               $\sim$5 watts

APPENDIX III

ANALYSIS OF THE BALLOON TO ORBITER LINK IN
THE COMMUNICATIONS AND TRACKING MODE

A. General

        After orbiter acquisition of the receive carrier, the
orbiter enters the communications and tracking mode. The conical
beam is selected; it tracks the carrier and transmits signals to
and receives signals from the balloon. Important parameters
associated with this link are presented in Table III-1.

        First the required signal-to-noise density ratios for
the ranging signal and the data subcarrier are determined. Then
the required carrier-to-noise ratio is derived. Since the system
effective noise temperature is known, the required carrier power
is determined from the value of the required carrier-to-noise
ratio. Modulation indices for the ranging signal and the data
subcarrier are chosen such that 1.0 db carrier suppression occurs
and the ranging and data subcarrier threshold simultaneously. The
total required power is calculated from the above derived values;
then the required balloon transmit power is derived for this mode.

B. Required Signal-to-Noise Density Ratio for Ranging

        For an unambiguous range of 4600 km, the PN ranging code
must have a minimum period of 30.7 msec. A code sequence composed
of a clock, an X component of bit length 15, and a Y component of
bit length 31 is proposed. The length of the combined code is
930 bits. The bit rate is then determined from the minimum code
period required; i.e., 30.7 msec. The resultant bit rate is
30 kbps or less. A 10 kbps rate is used here. The ranging
system proposed is not similar to that used in the DSN or MSFN.
The scheme is to generate the PN code in a set of sequence (component)
generators and combine them to form the composite sequence. The
combining logic is CL ⊕ XY and is accomplished in a composite PN
code generator.

        A similar generator is provided in the orbiter range
receiver. The receiver is clocked by a signal derived from the
received (transponded) range code. Word detectors are used to
detect a given state in the transmit and receive generators. The
detected state in the transmit generator provides a counter start
pulse, and the same detected state in the receiver generator
provides a counter stop pulse. During the time interval between
same state detections, the counter counts a frequency which will
provide the required resolution. This frequency is generated by an
on-board oscillator.

The acquisition time is computed by noting that the acquisition process searches through each sequence, one bit at a time, and that the longest sequence will establish the total time required   (i.e. the sequences are searched in parallel). The acquisition time, T_{acq}, can be shown as,[8]

$$T_{acq} = P_{31} \ \log_2 \left(P_{31} \right) \left(\frac{S_R T}{N_o} \right)_{req} C \ \frac{No}{S_R}$$

where: P_{31} = the length in bits of the Y sequence = 31 bits

$\log_2 P_{31}$ = 4.95

$\left(\frac{S_R T}{No} \right)_{req}$ = signal energy per bit to noise spectral density ratio for a given error rate

C = coefficient of correlation; for this particular code, $C=4$

$\frac{No}{S_R}$ = actual noise spectral density to ranging signal ratio calculated for the orbiter/probe/orbiter links

For a "good range data" probability of 0.999,

$$\left(\frac{S_R T}{No} \right)_{req} = 3.125$$

Substituting these constants into the equation yields,

$$T_{acq} = 2000 \ \frac{No}{S_R}$$

For an acquisition time of 2 seconds,

$$\left(\frac{S_R}{No} \right)_{req} = 1000 = 30.0 \ db$$

C. Required Signal-to-Noise Density Ratio for the Data
     Subcarrier

To achieve a bit error rate of 10^{-3}, the required
subcarrier signal-to-noise ratio $\left(\dfrac{S_D}{N}\right)$ is 7 db in a bandwidth
equal to the bit rate.[9] Thus,

$$\left(\frac{S_D}{N_o}\right)_{req} = 7 \text{ db} + 10 \log 60 = 24.8 \text{ db}$$

where $\left(\dfrac{S_D}{N_o}\right)_{req}$ is the required 10 kHz subcarrier signal-to-

noise density ratio at the orbiter antenna receive output.

D. Required Orbiter Receiver Carrier Tracking Loop
     Bandwidth and Carrier-to-Noise Density Ratio

Since the same carrier tracking loop is used in both
the search mode and the communications and tracking mode, identical
results are obtained. Thus,

$$2B_L = 830 \text{ Hz (with CNR}_L = 10 \text{ db)}$$

and

$$(CNR_o)_{req} = 38.3 \text{ db (referenced to 1 Hz)}$$

E. Required Receive Carrier Power and Total Power at
     the Output of the Orbiter Antenna

The required carrier power at the receive output of
the orbiter antenna is,

$$C_{req}(dbm) = (CNR_o)_{req} \text{ db} + 10 \log KT_{eff} \text{ (dbm)}$$

where:

$$(CNR_o)_{req} = 38.3 \text{ db};$$

$$T_{eff} = 2350°K$$

Therefore,

$$C_{req} = -126.6 \text{ dbm}$$

Allowing 1.0 db for carrier suppression due to modulation and 3.1 db for carrier circuit margin, the required total receive power (P_{tot}) at the receive output of the orbiter antenna is:

$$P_{tot} = -122.5 \text{ dbm.}$$

F. Modulation Indices

Using these results, the following equations can be written,

$$\left(\frac{S_R}{N_o}\right)_{req} + CM + X = 33.0 \text{ db} = 10 \log \left[P_{tot} \sin^2 (\theta) \, J_o^{\,2} (\emptyset) \right]$$

$$- 10 \log KT_{eff}$$

$$\left(\frac{S_D}{N_o}\right)_{req} + CM + X = 27.8 \text{ db} = 10 \log \left[2 \, P_{tot} \cos^2 (\theta) \, J_1^{\,2} (\emptyset) \right]$$

$$- 10 \log KT_{eff}$$

where:

$$P_{tot} = -122.5 \text{ dbm}$$

$$T_{eff} = 2350°K$$

Θ = phase modulation index of the ranging signal onto the carrier.

$\emptyset$ = phase modulation index of the data subcarrier onto the carrier.

CM   = ranging and data subcarrier circuit margin = 1.5 db

X   = allowable degradation in receive $\frac{S}{N}$ due to transmitted noise = 1.5 db

The above simultaneous equations are solved of Θ and $\emptyset$ such that both signals threshold simultaneously. Thus,

$$10 \log \left[\sin^2 (\Theta) J_o^2 (\emptyset) \right] = 33.0 + 122.5 - 164.9 = -9.4 \text{ db}$$

$$10 \log \left[2 \cos^2 (\Theta) J_1^2 (\emptyset) \right] = 27.8 + 122.5 - 164.9 = -14.6 \text{ db}$$

Solving for Θ and $\emptyset$ yields,

$$\Theta = 0.35 \text{ radians}$$

$$\emptyset = 0.30 \text{ radians}$$

G. Required Balloon Transmitter Power in the Communication and Tracking Mode

The required balloon transmitter power is calculated in Table III-2.

TABLE III-1

Balloon to Orbiter Link Parameters for the
Communications and Tracking Mode

a.   Frequency (nominal)   2300 MHz

b.   Balloon Line Loss   2 db

c.   Balloon Transmit Antenna Gain (at 3 db points)   1 db

d.   Path Length (maximum)   4600 km

e.   Orbiter Antenna Temperature   2350°K

f.   Orbiter Receive Antenna Gain (conical beam)   24 db

g.   Orbiter Line Loss   2 db

h.   Orbiter Receiver Noise Figure   6 db

i.   Minimum CNR_L in $2B_L$ 10 db

TABLE III-2

Calculation of Required Balloon Transmitter Power in
the Communication and Tracking Mode

Required Total Power (P_{tot}) at Receive Output of Orbiter Antenna	-122.5 dbm
Orbiter Antenna Gain (conical beam)	24.0 db
Space Loss (4600 km)	173.0 db
Balloon Transmit Antenna Gain	1.0 db
Balloon Line Loss	2.0 db
Required Balloon Transmitter Power	27.5 dbm
	$\approx$ 0.6 watt

APPENDIX IV

ANALYSIS OF THE ORBITER TO BALLOON LINK IN THE
COMMUNICATION AND TRACKING MODE

A.   General

        Unlike the balloon transmit power which is reduced in
the communications and tracking mode, the orbiter transmit power
remains unchanged at 3 watts. Other important parameters
associated with this link are presented in Table IV-1.

        First, the required signal-to-noise density ratio for
the ranging signal, and the carrier-to-noise density ratio for the
carrier are derived. Then the resultant circuit margins for these
signals are calculated.

B.   Required Signal-to-Noise Density Ratio for the Ranging Signal

        The required receive ranging signal-to-noise density ratio
plus circuit margin is 31.5 db on the balloon to orbiter link (see
Appendix III). To achieve this value the balloon transmit signal-
to-noise density ratio must be 37.0 db. Assuming a degradation of
1.0 db through the transponder, the receive ranging signal-to-noise
density ratio for the orbiter to balloon link is 38.0 db. Thus,

$$\left(\frac{S_R}{N_o} \right)_{req} = 38.0 \text{ db}$$

C.   Required Carrier-to-Noise Density Ratio

        Since the receiver parameters are the same in either
mode, the required carrier-to-noise density ratio is,

$$(CNR_o)_{req} = 38.3 \text{ db}$$

D. Modulation Index of Ranging Signal

A modulation index of 0.7 is chosen for the ranging signal on the orbiter to balloon link so that approximately the same circuit margins occur for both ranging and the carrier.

E. Total Receive Power at Output of Balloon Antenna

Since the orbiter transmitter total power output is 34.6 dbm in either mode, the total receive power at the output of the balloon antenna (P_{tot}) is calculated in Table IV-2.

F. Circuit Margins for the Carrier and Ranging Signal

Circuit margins for the carrier and ranging signal are calculated below.

$$\left(\frac{S_R}{N_o}\right) = 10 \log P_{tot} \sin^2(\Theta) - 10 \log K\, T_{eff}$$

$$= -114.6 \text{ dbm} + 10 \log \sin^2(0.7) + 166.3 \text{ dbm}$$

$$\left(\frac{S_R}{N_o}\right) = 47.9 \text{ db}$$

Therefore,

$$CM_R = \frac{(S_R/N_o)}{(S_R/N_o)_{req}} = 9.9 \text{ db}$$

Now,

$$CNR_o = -114.6 \text{ dbm} - 2.3 \text{ db} + 166.3 \text{ dbm}$$

$$= 49.4 \text{ db}$$

Therefore,

$$CM_C = \frac{(CNR_o)}{(CNR_o)_{req}} = 11.1 \text{ db}$$

TABLE IV-1

Orbiter to Balloon Link Parameters for the
Communication and Tracking Mode

a.   Frequency (nominal)   2100 MHz

b.   Orbiter Transmit Power into Transmission
         Line   34.6 dbm

c.   Orbiter Line Loss   2 db

d.   Orbiter Transmit Antenna Gain (conical beam)   24 db

e.   Path Length (maximum)   4600 km

f.   Balloon Antenna Temperature   1700° K

g.   Balloon Receive Antenna Gain (at 3 db points)   1 db

h.   Balloon Line Loss   2 db

i.   Balloon Receiver Noise Figure   6 db

j.   Minimum CNR_L in 2 B_L 10 db

TABLE IV-2

Calculation of Total Receive Power at the Output of the
Balloon Antenna in the Communication and Tracking Mode

Orbiter Transmitter Power	34.6 dbm
Line Loss	2.0 db
Orbiter Antenna Gain (conical beam)	24.0 db
Space Loss (4600 km)	172.2 db
Balloon Antenna Gain	1.0 db
Total Power at Output of Balloon Antenna (P_{tot})	-114.6 dbm

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